DP Flow Measurement
Still a Valid Flow Technology
in the 21st Century
DP Flow

What is DP flow measurement?

• Volumetric flow meter for gases and liquids
  – With the right transmitter, can be an inferred mass flow meter

• By definition, primary flow element creates a pressure drop

• Differential pressure (DP), or Multivariable transmitter: the flow meter
  – reads the pressure drop
  – Can convert output to linear flow rate by square root function (optional, by choice)
  – Transmits 4-20mA DP or flow rate, optional local display

• Receiver interprets 4-20mA transmitter output

• flow measurement used for control loops

• Very prominent technology in oil and gas and large pipes

• Mr. Bernoulli did the math (dead white guy)
Pressure Drop

- Instantaneous DP: what DP uses for a measurement
  - What the flow rate is calculated from
- Permanent Pressure Loss (PPL): inlet pressure minus recovered outlet pressure

Figure 2
Orifice Plate Installation with Pressure Profile
Permanent Pressure Loss

- Who cares?
- **Permanent Pressure Loss** uses up the energy that is supposed to transfer the fluid
- Energy – electricity or steam heat drives pumps or compressors
  - kinetic energy that creates the differential pressure that moves liquid/gas from a to b
- 40% of energy (in US) is used to pump or compress fluid
  - Lift water into standpipe, oil pipeline, pneumatic fluid power, refinery
- Typical 20 HP motor driving a pump costs $50,000/year in energy costs
- Users want to minimize the loss of pressure (PPL) inherent in measuring
- The lower the permanent pressure loss, the more efficient their energy usage.
PPL in orifice plates

- Beta ratio: orifice size/Line size or $d/D$
  - Generally Beta ranges of 0.25 to 0.7 for non-commerce; 0.3 to 0.6 for custody transfer
- Low Beta (ratio)
  - Small hole, higher DP, higher permanent pressure loss
  - Costs more to operate because of lost energy
- High Beta (ratio)
  - Big hole, lower DP, lower permanent pressure loss
  - Costs less to operate because of lost energy
- Every primary flow elements has characteristic PPL (unrecoverable) pressure loss
  - Rule of thumb, Orifice plates permanent pressure drop is about 50%
  - 100”wc drop at taps = 50”wc permanent drop
  - Who cares? People who pay for the pumping energy don’t want to lose it in a measurement

<table>
<thead>
<tr>
<th>Full-scale DP</th>
<th>Beta ratio</th>
<th>Increase in permanent pressure drop</th>
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</thead>
<tbody>
<tr>
<td>50 inches</td>
<td>0.60</td>
<td></td>
</tr>
<tr>
<td>100 inches</td>
<td>0.52</td>
<td>1.6 PSIG</td>
</tr>
<tr>
<td>200 inches</td>
<td>0.45</td>
<td>3.2 PSIG</td>
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</table>

Effect of full-scale DP on beta ratio and permanent pressure drop
Permanente Druckverlust

– Einige Primärstromelemente sind effizienter als andere:

![Diagramm: Normalisierte % Druckverluste vs. d/D-Verhältnis (Beta)]
Aspects of DP: Turn down

• Turndown – over what range of the meter is the reading accurate enough to use?
  – How low can the meter read before the error is so big the reading is garbage?
  – Calculated by Fullscale/minimum useable flow

• All % FS instruments are accurate at the ‘top end’ of the range
  – Accuracy as % FS (percent of full scale)
  – Lowest error is at the top end
  – Example: 0-250 gpm; 0.5% uncertainty
    • Error is at the top end: 1.25 gpm
    • At low end, at a flow rate of 10 gpm, a 1.25 gpm error is 12.5% of the reading

• Percent of reading instruments (Coriolis) have better turndown (not DP)
Aspects of DP: Turn down

• Technology advances have increased turndown for DP

• Flow profiling in advanced primary flow elements
  – Accelabar (pitot tube wedded to a flow nozzle)
  – FTI HHR Flow Tubes and FloPak
  – higher turn down range, up to 10:1

• Smart transmitters more stable at the low end
• Multivariable transmitters compensate for line pressure and temperature
Integrated Flow Nozzle and Pitot Tube

Veris Accelabar
- Averaging Pitot Tube element in a flow nozzle
- Flow nozzle conditions the flow
- Pitot Tube creates the DP
- Multivariable DP read DP, temperature, static pressure, generates mass flow rate value
- No upstream/downstream
- Pitot tube creates very low DP
  - Low permanent pressure loss
  - Goal when reducing energy costs
Wika/Fluidic Technique’s HHR

- Looks like a Venturi, but on steroids
  - permanent pressure loss (15-20% DP)
  - lower than OP, Flow nozzle, or Venturi

### OPERATING COSTS COMPARISONS

<table>
<thead>
<tr>
<th></th>
<th>16 INCH AIR LINE</th>
<th>BETA = 0.6446</th>
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<tr>
<td>DIFFERENTIAL</td>
<td></td>
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<tr>
<td>PRESSURE LOSS AT</td>
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<td>NORMAL FLOW (inches of</td>
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<td>water)</td>
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<tr>
<td>COEFFICIENT</td>
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<tr>
<td>OF DISCHARGE</td>
<td></td>
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<tr>
<td>PERMANENT</td>
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</tr>
<tr>
<td>DIFFERENTIAL</td>
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</tr>
<tr>
<td>PRESSURE LOSS (%)</td>
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<tr>
<td>POWER LOSS</td>
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<tr>
<td>AT NORMAL FLOW RATE (hp)</td>
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<tr>
<td>OPERATING</td>
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<tr>
<td>COST AT NORMAL FLOW</td>
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<td>($/Year)</td>
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<td>Orifice Plate</td>
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<td>HHR Flow Tube</td>
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<td>NORMAL FLOW (inches of</td>
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<td>water)</td>
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<tr>
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<tr>
<td>PRESSURE LOSS (%)</td>
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<tr>
<td>AT NORMAL FLOW RATE (hp)</td>
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<td>COST AT NORMAL FLOW</td>
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<tr>
<td>($/Year)</td>
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<td>Orifice Plate</td>
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<td>Flow Nozzle</td>
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<td>Venturi</td>
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<tr>
<td>HHR Flow Tube</td>
<td>26.1495</td>
<td>0.9872</td>
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</table>
Wika/Fluidic Technique’s HHR FlowPak

• velocity profiling technology
  – !!! No upstream/downstream straight run requirement !!!
  – Uncalibrated accuracy @ 0.5%
  – Translineal Flow plate - conditioning plate with lots of holes
  – Classic Venturi, permanent pressure loss (15-20% DP)
    • lower than OP, Wedge, Flow nozzle
  – Line sizes 3-36”

• Rules of thumb
  – Length is 5-6x the line size (3” line size is 18” long)
  – $800 - $1000 per diameter pipe inch

• How does it stack up to an orifice plate?
  – 2” HHR, takes 20” of line, $1800
  – 2” orifice plate, flange unions and meter run: $1800, about 5’ long
Wika/Fluidic Technique’s HHR FlowPak

- Very high coefficient of discharge
  - the closer to 1.00, the (more accurate the readings)
- Fits Wika’s pattern to compete at the top ‘value’ end of a given ‘commodity market’.
- Rule of thumb for cost? $800 - $1,000/line inch
  - Worth pursuing a 24” flow element
- Ever recommend lower diameter than line size for high velocity?
  - Yes and no
  - Wika FTI approach is to machine the tube with a smaller beta so line size stays the same, no reducers, no oddball piping
Measurement Advances

- Multivariable transmitter
  - Pressure and temperature compensation for gases and steam (inferred mass flow meter)
  - DP transmitter with
    - a temperature sensor, RTD or Thermocouple
    - Embedded absolute pressure sensor for static pressure compensation
    - math calcs to get inferred mass flow
  - Why is pressure and temperature compensation needed?
What are “Design Conditions”?

- DP flow measurement is made under “Design Conditions”
- Design Conditions are the *supposed* operational conditions
  - Temperature at operational conditions
  - Pressure at operational conditions
  - Viscosity at operational conditions
  - Density at operational conditions
- This data is the basis for “sizing the orifice plate”, or for calculating the DP at a given flow rate for any DP primary flow element
- Gas is compressible, liquids are not (for sake of process flow measurement)
- Guess how often real operational conditions do not match reality?
What happens when temp deviates from design cond?

- Flow error due to temperature deviation from design conditions (gas/steam)
What happens when pressure deviates from design cond?

- Flow error due to static (line) pressure deviation from design conditions (gas)
Principle: Mass accounts for density  
Volume does not

• All of you had a chemistry class
• Remember Avagadro’s number?
  – $6.023 \times 10^{23}$
  – Actual number of molecules in a mole
  – (not the furry little underground creature)
• That’s mass, the number of molecules
  – Weight is mass $\times$ acceleration of gravity
• Mass is important in the process industries because a mass measurement tells the chem eng how many moles are involved.
  – need the right number of moles to make product
  – Too few/too many moles: product or process problem
• As volume and density varies, mass varies
• gas/steam density varies with temperature and pressure
  – deviation from design conditions = error
**Multivariable Transmitter**

- Temperature changes can signal density changes in liquids
- Uses process “Design Conditions”
  - compensates for temperature and pressure deviations from design conditions
- Where do you use it?
  - Steam
  - Gases
  - Steam
  - Gases
  - Gases
Volumetric vs standard volume vs mass

- DP flow is a volumetric measurement
  - LPM, CFM, pounds per hour when design conditions prevail
- Multivariable can measure Standardized Flow
  - SCFM (Standard CFM), corrected to STP
- Multivariable can measure inferred mass flow
  - pounds per hour (steam, liquid), Kg/min, pounds/hour
- Prime Example of where mass measurement makes a difference
  - Steel Mill
  - Gas flows need to be ratioed
  - 20 year old control scheme using DP flow and ratio control
  - They are constantly adjusting flows over time due to temperature deviations from design conditions
  - Reason for problems?
    - Process needs X molecules mass to work
    - Measurement is volumetric flow, uncompensated for line pressure or temperature
  - Solution – mass flow measurement with MultiVariable
**DP Flow**

Why do people still use DP rather than the alternatives?

**Answer:** works where other technologies do not

- Magnetic: medium must be conductive, hydrocarbons are not; no steam
- Vortex: medium must be clean and low viscosity, temp limit 240°C/465°F
- Turbine: clean medium, lubricity issues, viscosity/density limits,
  - Likes cold, no steam
- Thermal dispersion: typically gas only (can do liquids), limited to lower temperatures, no steam, no wet medium (liquid droplets in gas are killers)
- Positive displacement: media, no steam, limited line sizes.
- Ultrasonic clamp-on: temperature limits, no steam, min line pressure for gas
- Coriolis: no steam, larger line sizes prohibitively expensive
Review - DP Flow

Where does DP shine?

• High temperatures; when other technologies can’t take the heat in the kitchen
  – Steam, high temp liquids, DowTherm (heat transfer medium)
  – When it’s a hot process, long impulse tubing keeps the DP transmitter within operating limits

• Works at pressures up to xmtr body ratings (4,500psig @ 260°F, derated above)

• Large line sizes
  – Ever hear of a 24” Coriolis meter? (10” Coriolis fits takes up the 8’ bed of full size pick-up truck)
  – What else will you use?

• Multivariable does temp/pressure compensation for gases, steam

• Installation: Hot tap option for Averaging Pitot tube

• Huge knowledge base from 90 years of use
  – In customer’s comfort zone, been around a long time generally very well understood
  – “Our guys understand DP”
Review - DP Flow - downside

• Low turndown without ‘advanced’ primary element (Accelabar)
  – Generally not good for low velocity, low flows, low Reynolds numbers
• Always some pressure loss (permanent pressure loss a fraction of DP)
• Measurement affected by changes in
  – density and viscosity
  – Pressure and temperature for gases and steam
• Straight run upstream/downstream requirements for flow conditioning
  – Stricter for custody transfer than the normal 10 up/5 down (45up, 20 down)
• No integral totalizer in the flowmeter (DP/SMV xmtr)
  – Use a totalizing meter (PD785) or PLC/DCS totalizes
• Maintenance
  – Primary flow element damage (orifice plate edge damage)
  – impulse tubing leaks
  – 3 valve manifold - scale clogs the valve ports
Summary - DP Flow

• Alive and well in the 21st century
• Holding its own in the flow technology line-up
• Advanced technology primary flow elements
  – lower Permanent pressure Loss
  – higher turndown
  – zero up/zero down installation requirements
• MultiVariable transmitters can infer a mass flow measurement
Review - MultiVariable

- Where does Multivariable shine?
- Gas and steam applications where mass flow is the needed due variable temperatures and pressures, not volumetric flow
What Lesman stocks

- All are SS, Silicone fill, FM/I-S, 4-20mA HART, push buttons, basic display, mtg bracket
  - Basic display shows flow units
  - DP: Footballs, Vents: Dual Ended heads, Std Vent/Plug, Side/End
  - Temperature: isolated RTD/T-C,
- Qty 1, STG73L, 0.5-50psi, in-line gage
- Qty 3, STG74L, 5-500psi, in-line gage
- Qty 1, STG77L, 30 -3000psi, in-line gage
- Qty 10, STD720, 4-400in wc, DP
- Qty 1, STD730, 1-100psid, DP
- Qty 1, STD810, 0.1-10inwc draft range, DP
- Qty 1, STT850, RTD/T-C Temperature
- Most people should use gage pressure for vacuum, not absolute
Single vs Dual ended head

- Process head (some call it ‘flange’)
- Tapped ¼” NPT on both ends: dual ended head
- Allow the installer to connect impulse tubing from either side

Lower side vent (drains liquid)
Process ½” NPT
Football:
Adapts ¼” NPT Flange to ½”NPT

End mounted
Drain/Vent Valve

No side mount vent
Vents and Drains

- Vents and drains remove gas or liquid from the process head
- When fluid is both gas and liquid
  - Gas rises, Liquid falls
- To vent gas from liquid flow, vent is on the high side
- To drain liquid from gas flow, drain vent is on the low side
- Tubing fits over the center vent to contain and direct the release
# Vents and Drains

- When

## Vents and Drain Type/Location

<table>
<thead>
<tr>
<th>Head Type</th>
<th>Vent Type</th>
<th>Location</th>
<th>Vent Material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Ended</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>$0</td>
</tr>
<tr>
<td>Single Ended</td>
<td>Standard Vent</td>
<td>Side</td>
<td>Matches Head Material</td>
<td>$38</td>
</tr>
<tr>
<td>Single Ended</td>
<td>Center Vent</td>
<td>Side</td>
<td>Stainless Steel Only</td>
<td>$118</td>
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<tr>
<td>Dual Ended</td>
<td>Standard Vent</td>
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<td>Stainless Steel Only</td>
<td>$118</td>
</tr>
<tr>
<td>Dual Ended</td>
<td>Std Vent/Plug</td>
<td>Side/End</td>
<td>Matches Head Material</td>
<td>$38</td>
</tr>
</tbody>
</table>

End Vent Plug

Side Vents & Plug

Direction of vent gas/fluid

Single Ended Head

![Image](image.png)
Vents and Drains

Standard Vent/Drain

Center Vent/Drain

Vents and Drains material

No grooves Stainless Steel

One groove Monel

Two grooves Hastelloy
# Vents and Drains

The vent/drain locations

<table>
<thead>
<tr>
<th>Head Type</th>
<th>Vent/Drain Location</th>
<th>Vent Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Ended</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Single Ended</td>
<td>Side w/Vent</td>
<td>Matches Head Material(^1)</td>
</tr>
<tr>
<td>Single Ended</td>
<td>Side w/Center Vent</td>
<td>Stainless Steel Only</td>
</tr>
<tr>
<td>Dual Ended</td>
<td>End w/Vent</td>
<td>Matches Head Material(^1)</td>
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<tr>
<td>Dual Ended</td>
<td>End w/Center Vent</td>
<td>Stainless Steel Only</td>
</tr>
<tr>
<td>Dual Ended</td>
<td>Side w/Vent &amp; End w/Plug</td>
<td>Matches Head Material(^1)</td>
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<table>
<thead>
<tr>
<th>Type/Location</th>
<th>HIGH PRESSURE</th>
<th>LOW PRESSURE</th>
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<th>LOW PRESSURE</th>
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<td>6</td>
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Mounting location

- When fluid is both gas and liquid
  - Gas rises
  - Liquid falls
- To vent gas from liquid flow, vent is on the high side
- To drain liquid from gas flow, drain vent is on the low side

Rules:

Table 7 – Suggested Connection Locations

<table>
<thead>
<tr>
<th>Process</th>
<th>Suggested Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gases</td>
<td>Above the gas line.</td>
<td>The condensate drains away from the Transmitter.</td>
</tr>
<tr>
<td>Liquids</td>
<td>Below but near the elevation of the process connection.</td>
<td>This minimizes that static head effect of the condensate.</td>
</tr>
<tr>
<td></td>
<td>Level with or above the process connection.</td>
<td>This requires a siphon to protect the Transmitter from process steam. The siphon retains water as a fill fluid.</td>
</tr>
</tbody>
</table>
Mounting Location

Mounting Location for fluids:
- **Liquid**: Tap valve, Union or flange, 3-valve manifold, Drain valve, Orifice, Drain plug
- **Gas**: Tap valve, Union or flange, Tee, Orifice, Condensate pot
- **Steam**: Tap valve, Union or flange, Tee, Orifice, Condensate pot
When fluid is both gas and liquid:
- Gas rises
- Liquid falls

To vent gas from liquid flow, vent is on the high side.
To drain liquid from gas flow, drain vent is on the low side.

Rules:
- Mounting Location
- Blocking Valves
  - Plugged Tee for Steam Service for Sealing Fluid
- Blowdown Valves
- Sufficient Length for Cooling
- Vent/Drain (When Selected)

**STEAM SERVICE**

**GAS SERVICE**

**LIQUID SERVICE**

Flow

Vent/Drain (When Selected)